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Aerodynamic Examination of the Laryngeal Function

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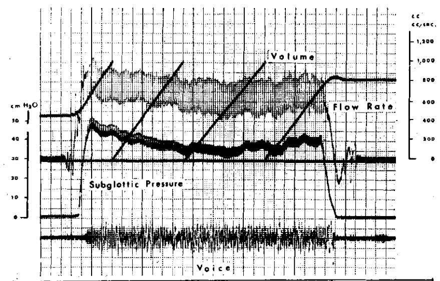
Since ineffective utilization of the air flow at the glottis is one of the determinant factor of voice disorders, aerodynamic examinations of phonation provide significant clinical information on many aspects of vocal dysfunction.

For the simultaneous registration of the physical parameters of phonation, a polybeam recording system was designed. A penumotachograph system is used for the recording of air flow rate, the integration of which gives air volume. Subglottic pressure can be transmitted to a pressure transducer via either tracheal needle or tracheostomia. The pressure transducer converts subglottic pressure into an electrical signal. The vocal signal was fed into one of the channel through a tape recorder. From the recorded data, we can calculate glottal resistance and subglottic power. The glottal resistance is defined as ratio of subglottic pressure to flow rate. Tension and stiffness of the vocal cord, and the shape of the glottis during phonation mainly regulate the glottal resistance. The subglottic power is the product of subglottic pressure times flow rate. The subglottic power stands for the expiratory power during phonation which is controlled by expiratory effort. These relationships between the air flow rate, subglottic pressure, subglottic power, and glottal resistance indicate that flow rate is determined by the interaction between expiratory power and glottal resistance.



	Flow Rate	Gl. Resistance	Subgl. Power
Laryngeal Stenosis	534-804	42-59	212 - 326
Normal Subject	50-200	20-290 $\frac{dyne\ sec}{cm^5}$	5-40 $\times 10^{-1}$W

Fig. 1

Fig. 1 shows the simultaneous recording of the flow rate, volume of air, subglottic pressure, and vocal signal during easiest phonation, obtained from a patient with laryngeal stenosis. It can be known that higher flow rate and comparatively elevated subglottic pressure resulted in higher subglottic power and lower glottal resistance than those of normal subjects.

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In the two cases shown in Fig. 2, the maked high flow rates were attributed to the low glottal resistance, while the subglottic power remained within normal range. The upper case was a patient with the left vocal cord paralysis of intermediate position and the lower case with the vocal cord tumor located near the anterior commissure which impeded complete closure of the glottis during phonation.

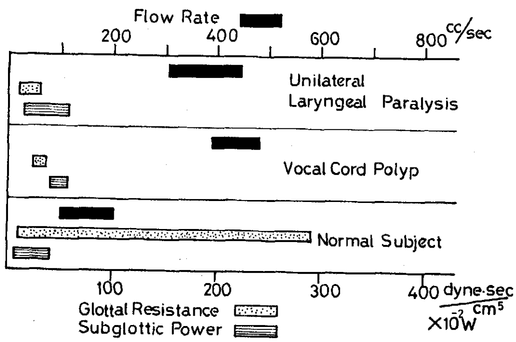

Fig. 2

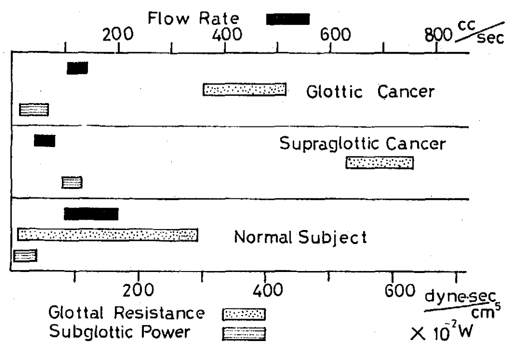

Fig. 3

In contrast with above mentioned dysfuncting pattern, we found that relatively low flow rate was caused by abnormally high glottal resistance. The first case shown in Fig. 3 was a patient haveing left vocal cord cancer. The cancer infiltrated diffusely and the glottal closure during phonation was confirmed to be very tight. The second case had an extended supraglottic tumor which impeded visualization of the glottic area.

On the basis of these results, it is assumed that unbalance between glottal resistance and expiratory power is the underlying patho-physiological mechanism of voice disorders. Usually, abnormally high flow rate is attributable to low glottal resistance while low flow rate to very high glottal resistance.

These assumptions could be supported by comparative studies on the air flow rate and glottal area measurements made by ultrahigh speed films of the vocal cord vibration. The area changes shown by the upper curve of Fig. 4 indicates that the glottis remained open throughout vibratory cycles. In addition, slow approxi-

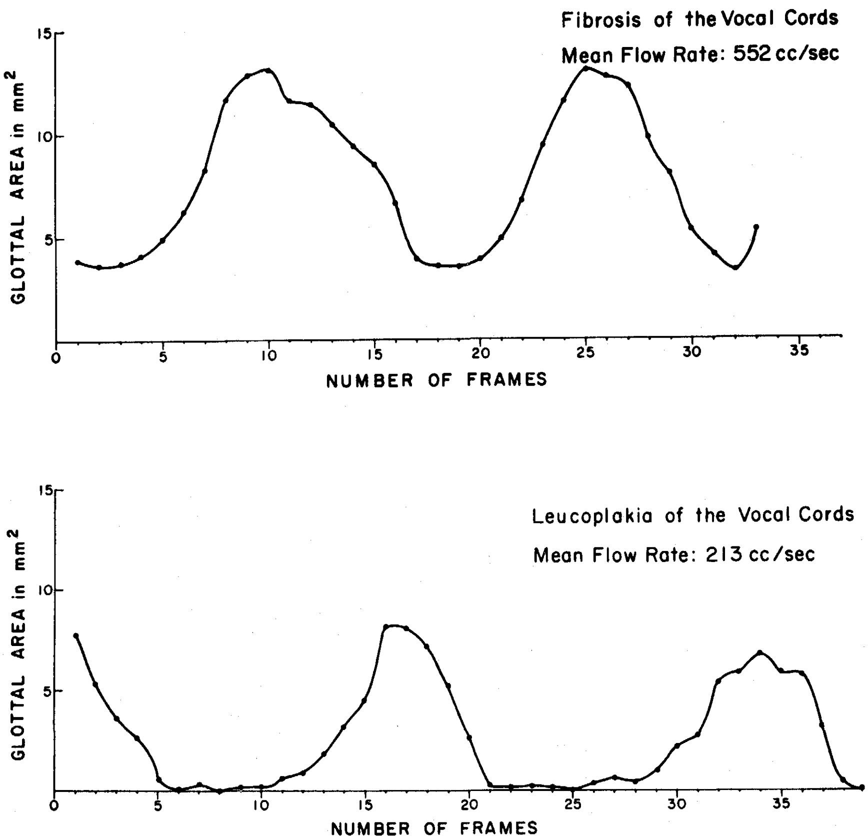

Fig. 4

mation of the vocal cords and large amplitude of the vibration induced wider area changes during vibratory cycle. In the lower case, the area change is charaterized by long closed periods, fast approximation of the cords and smaller amplitude of the vibration. The total area change in the upper case during a vibratory cycle appeared to be 3 times that of the lower case. The difference of the glottal area changes which represents the glottal resistance, is directly related to the divergence

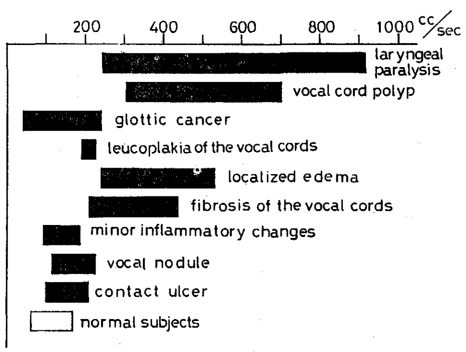

Fig. 5

in flow rate.

The results of flow rate measurements in various laryngeal diseases are summarized in Fig. 5. This figure indicates that flow rates in subjects with vocal disorders tend to vary depending upon the laryngeal pathology. Flow rates in the cases with vocal cord paralysis and with vocal cord polyp are much greater than the flow rates of normal subject. The patients with vocal nodule, with minor inflammatory change, and with contact ulcer showed the flow rates within the normal range or slightly extended beyond the normal limit.

Table 1

	Mean Air, Flow Rate in cc/sec	SD	95% Confidence Interval in cc/sec	Total Volume of Air Used in cc	Maximum Phonation Time in sec	Leakage of Air in cc	Time Lag in sec
Before operation	585.0	54.3	642.2•527.8	733	1.33	66	0.26
Two weeks postop	142.9	41.8	152.9•132.9	2030	14.79	0	0
One month postop	185.5	29.7	195.2•175.8	1850	10.22	0	0

Summary of Aerodynamic Findings before and after the Injection of Teflon Paste

Measurements of air flow rate before and after a functional laryngeal surgery has particular clinical value. Thable 1 summarizes the results of aerodynamic studies of a patient with unilateral vocal cord paralysis before and after the injection of Teflon paste. The restoration of vocal function after this treatment was demonstrated objectively. Decrease in flow rate after the injection was associated with increase in the total volume of air and with extension of the maximum phonation time.

Our investigations on normal subjects revealed that the following physiological primiciples were involved in maximally sustained phonation.

1) There is a significant linear correlation between the phonation volume and vital capacity. The phonation volume means the total volume of air for maximally sustained phonation.

2) The maximum phonation time varies in proportion with the amount of the flow rate and phonation volume.

3) The mean flow rate during phonation shows little variability among different subjects at median pitch and moderate intensity.

In order to represent the abnormalities in the over-all vocal function of the patients, deviations from the normal value in the phonation volume and phonation time were determined by ratio of phonation volume to vital capacity, PV-CV ratio, and phonation time ratio. The mean value of the flow rate is 110 cc/sec in the normal male and 100 cc/sec in the normal female. The average PV-VC ratio is 67 percent in the normal male and 59 percent in the normal female. When we know the vital capacity of a person, we can approximate maximum phonation time of the person, which we called predicted maximum phonation time. The ratio of

Table 2

Case No.	PV/VC ratio in %	Phonation time ratio in %	Mean flow rate in cc/sec
1	91	53	310
2	37 (75*)	17 (42)	370 (250)
3	90 (68*)	60 (62)	246 (196)
4	95 (65*)	24 (54)	630 (170)
5	75*	42	304
6	85	34	347
7	27 (68*)	9 (60)	534 (186)
8	78*	14	915
9	85	44	305
10	48	36	461

Results of the functional examination in patients with unilateral vocal cord paralysis. Postoperative results in parentheses. The asterisk indicates normal values of the PV-VC ratio.

Case No.	PV/VC ratio in %	Phonat. time ratio in %	Mean flow rate in cc/sec
1	93	74*	224
2	87	75*	118*
3	86	68	180
4	72*	82*	156*
5	75*	79*	155*
6	48*	62	149*
7	80	99*	134*
8	78*	109*	115*

Results of the functional examination in patients with vocal nodules. Asterisk indicates normal values.

measured phonation time to predicted phonation time is named phonation time ratio. When this ratio decreases under 70 percent, the duration of phonation is thought to be abnormally short.

This functional examination of ten patients with unilateral paralysis of the larynx indicates a very high flow rate and a marked reduction in the phonation time ratio. In contrast to these consistent findings in the mean flow rate and phonation time ratio, the PV-VC ratio varied considerably from case to case. The PV-VC ratio was significantly elevated in five cases, normal in two cases and very low in three cases (Table 2). These findings suggest that in patients with unilateral vocal fold paralysis, the disability may include abnormalities in the expiratory air supply during phonation as well as changes in the glottal resistance. In patients with vocal nodules the impairment in vocal function is generally slight. The mean flow rate and phonation time ratio remain usually within normal ranges. The PV-VC ratio, however, may be raised frequently beyond the normal limit (Table 2). The high PV-VC ratio in these patients proves that the expiratory effort during phonation is excessive to overcome the effect of the nodule at the glottis.

An analysis of our data obtained from more than one hundred patients justified the following diagnostic implications.

1) Flow rate more than 300 cc/sec with phonation time ratio less than 50% suggests that a low glottal resistance is the dominant contributing factor for the vocal dysfunction which may be diagnosed as hypofunctional voice disorder.

2) Flow rate up to about 250 cc/sec with phonation time ratio of more than 70% and with high PV-VC ratio suggests that a high glottal resistance is the dominant contributing factor for the vocal dysfunction which can be labelled as hyperfunctional voice disorder.

In conclusion, it should be emphasized that aerodynamic examinations on phonation can be a valuable adjuct to other physiologic studies for an understanding of laryngeal disorders.

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